# AN OVERVIEW OF ANATOMICAL CONSIDERATIONS OF INFANTS AND CHILDREN IN THE ADULT WORLD OF AUTOMOBILE SAFETY DESIGN[§]

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## Abstract

The infant and child differ structurally from the adult in a number of ways which are critical to the design for protection against impact forces and for adequate occupant restraint systems. The purpose of this paper is to bring together a profile of the anatomy, anthropometry, growth and development of the infant and child. Age differences related to the proper design of child restraint systems are emphasized. Problems discussed include child--adult structural differences, center of gravity of the body, the head mass in relation to the neck and general body proportions, positions of key organs, and biomechanical properties of tissues.

## Introduction

Infants and children are not miniature adults. Body size proportions, muscle bone and ligamentrus strengths are different and thus occupant packaging for crash protection need special consideration. This paper is an overview of pediatric size and proportional differences with considerations of some child injuries in car crashes along with a review of some biomechanical data.

## GROWTH OF THE INFANT BODY AS A WHOLE

Growth and development of the human body occurs continuously from birth through senesence (old age). Such development is sporadic and non-uniform, yet it does not occur haphazardly. For the most part, incremental growth of any dimension or part of the body occurs according to predictable trends. Most body dimensions

[§]This paper is a modification and update of "Infants and Children in the Adult World of Automobile Safety Design: Pediatric and Anatomical Considerations for Design of Child Restraints", Burdi, AR, Huelke, DF, Snyder, RG, et al, J Biomech. 2:267-280, 1969.

follow trends which involve rapid growth separated by a period of relatively slower or uniform growth. There are notable differences in the timing of these incremental growth spurts, for most tissues and organs of the body collectively reflect the general body growth. As an example, the brain grows rapidly during the period before birth and then slows considerably during the per-school years. At birth the brain is typically 25% of its adult size, although the body weight of the newborn is only about 5% of adult weight (Stuart and Stevenson, 1950). Importantly, about half of the postnatal growth of the brain volume occurs during the first year of life, and attains about 75% of its adult size by the end of the second year. By contrast, genital organs develop very slowly during this period but, instead, reach their adult size during the second decade of life.

Subcutaneous tissue (body fat) is a body component infrequently considered as a factor in the proper design of protective devices for the infant body. This tissue tends to increase rapidly in thickness during the first nine months following birth, which growth of the body as a whole is much slower. After this period of high incremental change there is a period of less rapid growth, so that by five years of age the thickness of the subcutaneous layer is about half the thickness of the nine month old infant.

Loading of the body by strap-type restraints must occur in areas where the body is strongest, i.e., on solid skeletal elements. In some, the fatty subcutaneous tissue can produce bulges or 'rolls' of flesh in the areas of placement on such restraint straps. Thus, proper positioning of restraint straps on the chubby 1-3 year old may be difficult to maintain because of the abundance of this fatty tissue.

Changes in body weight similarly follow characteristic age group trends (Krogman, 1960; Krogman and Johnston, 1965; Martin and Thieme, 1954; and Meredith, 1963). From the 10th day after birth, when the post-birth weight loss is usually regained, there is a steady increase in weight so that during the first three months an average baby gains about two pounds per month, or nearly one ounce per day (Krogman 1941). At five months the birth weight has doubled. Beginning at six months, there is only a one pound gain per month in weight so that the birth weight is tripled at the end of the first year and quadrupled at the end of the second. From this time on, the rate of increase in body weight gradually decreases during the 2nd year according to a factor of one-half pound per month (Krogman and Johnston, 1965). After the 2nd year gain in weight may become irregular and less predictable on a monthly basis. As a general pattern, after the 2nd year and until the 9th year there is a five pound annual increment. Thus, at 5 years the body weight is six times the birth weight and in the 10th year the weight of the body is ten times the birth weight (Krogman, 1960).

Changes in body height and body proportions also have specific age trends (Figs. 1-3). The newborn child is approximately 20 inches in total body length. During the first year this height is increased by approximately ten inches. Until about the seventh year, total body length should be doubled by the 4th year and tripled by the 13th year. The height of an adult is about twice the height of a two-year-old child. From the second to the 14th year, total body height increases (in inches) according to the formula: Height=age in years X 2.5 + 30 (Weech, 1954).

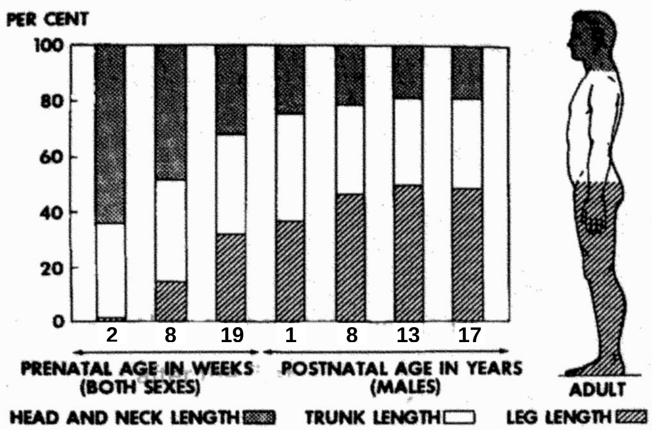


Fig. 1. Percentage distribution of body segments as related to pre- and postnatal development. (Modified from Salzmann, "Principles of Orthodontics.")

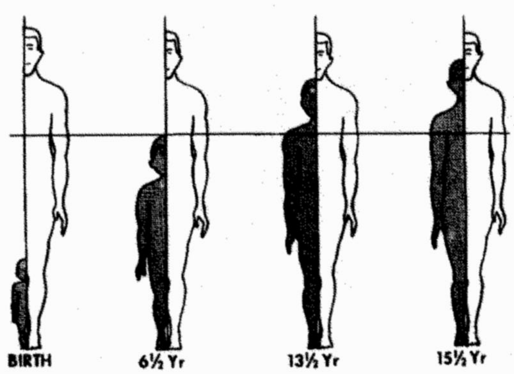


Fig. 2 Increase in total stature at various ages as compared to the adult. (Modified from Chenoweth and Selrick, "School Health Problems.")

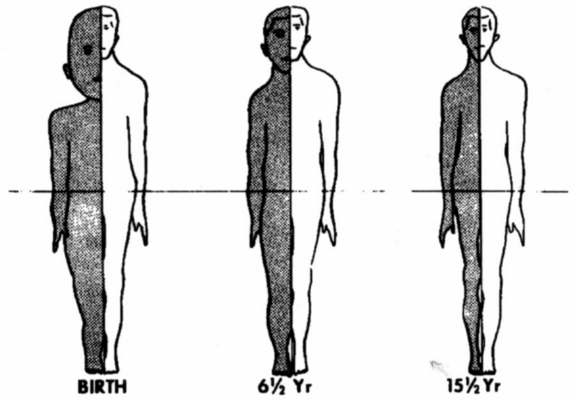


Fig. 3 Developmental change in body proportions as seen in direct comparison between the adult and the newborn, child and adolescent. (Modified from Chenoweth and Selrick, "School Health Problems.")

Age changes in the ratio between sitting (trunk) height and total body height cannot be overlooked when considering the dynamics of changing body proportions. (Fig. 4). Sitting height represents about 70% of the total height at birth, but falls rapidly to about 57% in the 3rd year. At 13-years of age in girls, and two years later in boys, the ratio of sitting height to total body height is about 50%.

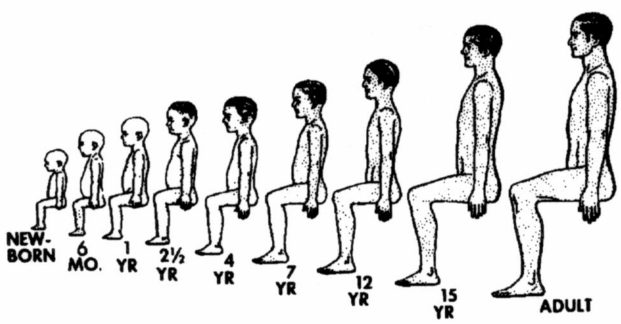


Fig 4 Changes in sitting height from birth to adulthood.

Longitudinal growth of limb bones occurs as long as the epiphyseal cartilage prolificates; growth ceases when the cartilage ossifies and fuses to the bone segments surrounding it. Since the fusion of epiphyses in the lower extremities occurs earlier in girls than in boys, girls tend to have a lower 'sitting height-total body height' ratio than boys, between eight and 12 years, and a higher one between the 14th and 18th year.

Thus, especially in the early years of life, the infant is markedly elongating in stature. Also, the postural changes of the infant, from a recumbent one to that of a slouched, upright position, is completed within a relatively short period of time.

In general, children of either sex are of the same height, weight, and general body proportions up to 10 or 11 years of age; yet, not infrequently one sees girls slightly taller than their male counterparts even at ages 6-10. Girls tend to have an earlier pubertal growth spurt between 11 and 14 years and, in general, are taller than boys of this age. In the early to mid-teens, the boys catch up, and then surpass the girls in stature (Watson and Lowrey, 1967). These variations in total height at the 10-14 year age span reflect the differences in sitting height between boys and girls.

At birth the head is one-fourth the total body length, whereas in the adult it is one-seventh (Fig. 5). Also the trunk is long with the

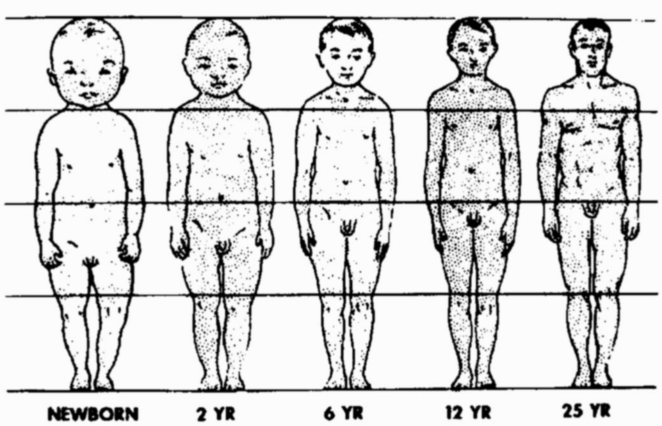


Fig 5 The proportional changes in body segments with age.

upper limbs being longer than the lower limbs. From the second half of the first year to puberty the extremities grow more rapidly than the head. At puberty the growth rates of the trunk and limbs are about equal, but the trunk continues to grow in length after limb elongation has declined in the adolescent period. The mid-point of the body is slightly above the umbilicus (navel) in the newborn, and a 2 years the mid-point of the body is slightly below the umbilicus; at about 16 years, this mid-point is near the pubic symphysis.

The center of gravity of the child varies according to age, child size, weight, and body form as well as sitting posture. A study by Swearingen and Young (1965), of individuals at ages 5, 10, 12, and 18 years, indicated that the center of gravity (CG) cannot be located accurately and precisely in groups of seated children. They found that a plot of the CG would fall within an asymmetrically ellipsoidal area. In these children it was found that the CG was located vertically on the torso well above the lap belt level. This high CG in children must be considered when adult lap belts are used to restrain children, since the greater body mass above the belt may cause the child to whip forward more than in the case of an adult. In a subsequent study of infants aged 8 weeks-3 years, it was found that the CG is located even higher on the body (Young, 1968).

## THE HEAD

In automotive collisions, the child's head is the body area most frequently and most seriously involved. In a study of children's injury patterns in 14,520 rural automobile accidents involving 31,925 occupants, it was found that children (birth through 11 years) had a frequency of 77% head injuries (Moore et al, 1959). This was a much greater frequency than either adolescents (69%) or adults (70%) in this study, although it was found that child head injuries were of a more minor variety than either adolescents or adults. Agran and Winn (1987) identified head injuries in 50% of children, either lap-shoulder belted or unrestrained. Contributing to specific head impact problems are the large head of the child, the relatively soft, pliable, and elastic bones of the cranial vault, and the fontanelles. As compared with the adult, these features make the head of the child less resistant to impact trauma. In a collision, for example, the unrestrained child, because of his large head and high CG, would 'lead with his head'. Crash data covering infants and children up to 4 years of age indicate that 77% of those who were injured in automobile accidents had head injuries (Kihlberg and Gensler, 1967).The vulnerability to injury of an infant's head occurs even prior to birth, as has recently been shown in a study of fetal deaths involving restrained and unrestrained pregnant women in auto accidents (Crosby et al, 1968). The reasons for this greater frequency of head injury in children can be demonstrated both anatomically and biomechanically. The child's head is proportionately larger than in the adult (Young, 1966), (Fig. 5). This heavier head mass and resulting higher seated CG in young children, coupled with weaker neck supporting structures, may be, in part, the basis for this higher frequency of head injury.

At birth the facial portion of the head is smaller than the cranium having a face-to-cranium ratio of 1:8 (cf. adult ratio of 1:2.5). Relative to the facial profile, the newborn forehead is high and quite bulged, due to the massive size of the frontal lobe of the brain (Fig. 6). Thus, in the newborn and infant the face is tucked below the massive brain case (Fig. 7). The large head-small face pattern is noticeable in children even up to ages 7 and 8. Vertical growth of the infant face occurs in spurts as related to both respiratory needs and tooth eruption. These growth spurts occur during the first 6 months after birth, during the 3rd and 4th year, from the 7th to 11th year, and again between the 16th and the 19th year. The first growth spurt is chiefly olfactory as associated with the vertical growth of the upper portion of the nose and nasal cavity. The last spurt is related to adolescent sexual development.

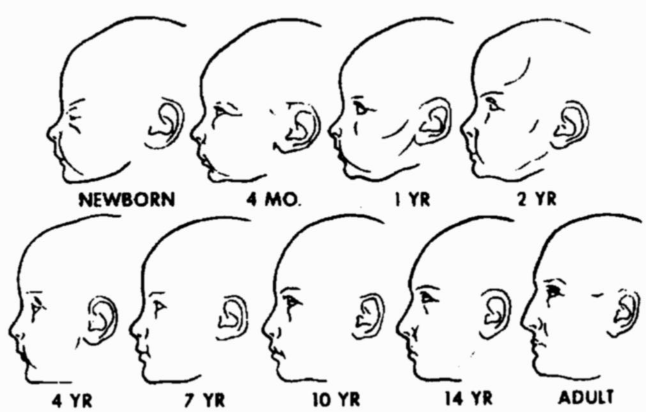


Fig. 6 Soft tissue profile changes of the head and face.

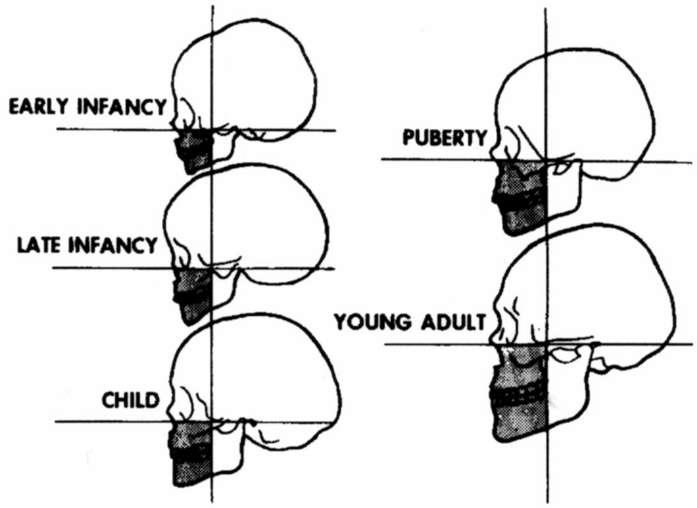


Fig. 7 Sequential changes of various head and face regions.

Infant head shape also differs significantly from that of the adult (Fig 8). In the infant the cranium is much more elongate and bulbous, with large frontal and parietal (side) prominences (Fig. 8). At birth the circumference of the head is about 13-14 inches. It increases by 17% during the first 3 months of life, and by 25% at 6 months of age. It increases by about 1 inch during the 2nd year, and during the 3rd through the 5th year head circumference increases by about one-half inch per year. There is only a 4 inch increase in herd circumference from the end of the 1st year to the 20th year (Fig 9).

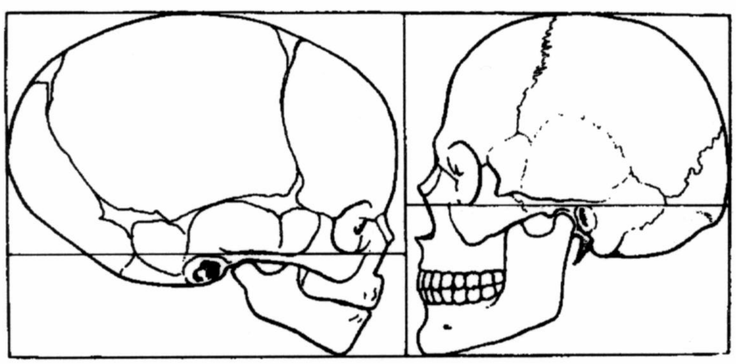

Fig. 8. A comparison of face-braincase proportions in the child and adult. The horizontal line passes through the same anatomical landmarks on both skulls.

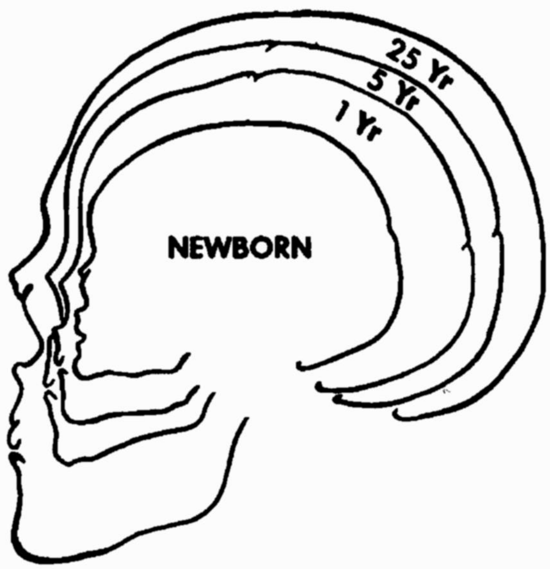


Fig. 9. Skull profiles showing changes in size and shape.
(Modified from Morris' "Human Anatomy.")

Head circumference increases markedly during the first postnatal year due to the progressive and rapid growth of the brain as a whole. The important relation of brain size and cranium size can be demonstrated on a percentage basis, which shows that 70% of the adult brain weight is achieved at 18 months, 80% at 3 years, 90% at 5-8 years and approximately 95% at the 10th year. In the adult the average brain weight is 1350 g.

Infant and child skulls are considerably pliable, due to the segmental development and arrangement of the skull bones, plus the flexibility of individual bones which are extremely thin. The skull develops as a loosely joined system of bones formed in the soft tissue matrix surrounding the brain. Junctions between bones are relatively broad and large, leaving areas of brain covered by a thin fibrous sheath and somewhat exposed to the external environment. These 'soft spots' (fontanelles) are several in number and are most obvious in the frontal and posterior skull regions (Fig. 10). The mastoid fontanelle, between the occipital and parietal bones, closed about 6-8 weeks after birth. However, a much larger midline junction between the frontal and parietal bones, i.e., frontal fontanelle, is not closed by bone growth until approximately the 17th month.

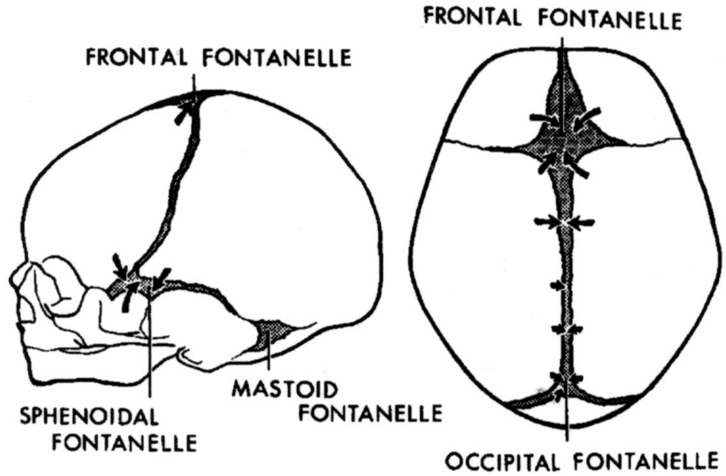


Fig. 10 Size and location of the fontanelles.
Arrows indicate direction of fontanelle closure.

At birth all of the potential structures for the development of teeth are present. The early teeth first erupt at bout 6 months of age and continue to erupt progressively. The child begins to lose his deciduous teeth about 5-6 years of age after which they are replaced by the permanent teeth.

Trauma to the jaws of infants or small children, especially in the area where the unerupted teeth are found can lead to serious problems in tooth eruption, tooth spacing, tooth arrangement and alignment. Traumatic injuries to the child's lower jaw (mandible) may be related to abnormal facial profiles with increasing age. The normal changes in size and position of the lower jaw are dependent upon a growth site in the mandible located near its junction with the skull. If this important growth site is significantly traumatized, the normal changes in size and position of the mandible diminish resulting in a smaller mandible and a recessive chin.

## THE NECK

There are several unique aspects of the anatomy of the child's neck. Neck muscle strength increases with age yet, with the greater head mass perched on a slender neck, the neck muscles generally are not developed sufficiently to dampen violent head movement, especially in children. In a study of lap-shoulder belted children, ages 10-14 years in all types of motor vehicle crashes, about 21% had cervical strain (Agran & Winn, 1987). The neck vertebrae of children are immature models of the adult. These cervical vertebrae are mainly cartilaginous in the infant, with complete replacement of this cartilage by bone occurring slowly. Articular facets, the contact areas between the vertebrae, are shallow; neck ligaments, as elsewhere in the body, are weaker than in adults. The disproportionately large head, the weak cervical spine musculature, and laxity, can subject the infant to uncontrolled and passive cervical spine movements and possibly to compressive or distraction forces in certain impact deceleration environments. These all contribute to a high incidence of injury to the upper cervical spine as compared to the lower cervical spine area (Sumchi and Sternback, 1991).

The articular facets of the infant and young children are oriented in an even more horizontal direction than in the adult (Kasai, et al, 1996) (60 deg. @ 1 year, 53 deg. @ 3 years and 47 deg. @ 6 years). The "cervicocranium", the base of the skull, C1, C2 and the C2/C3 disc is a distinct unit in infants and small children, and should be considered as a specialized area of the cervical spine because of its anatomical difference from the lower and more uniformly shaped cervical vertebrae (Huelke, et al, 1992). Using dynamic cervical spine radiographs it has been shown that the fulcrum for flexion is at C2-C3 in infants and young children, at C3-C4 at about age 5 or 6 and at C5-C6 in adults (Baker and Berdon, 1966).

In that the skull base, C1 and C2 move as a unit in flexion and extension, and in some rotation, it is not surprising that anterior displacement of the entire cervicocranial unit can occur after traumatic disruption of the posterior portions of C2, causing separation of the neural arch ossification centers, stretching of the elastic ligaments, or bilateral fractures of the pedicles without evidence of dislocation (Sumchi, and Sternbacck, 1991). A distraction force on the cervical spine can pull apart the cervical cartilagenous-osseous structures and associated ligaments and, if in a forward direction, can cause spinal cord damage (Finnegen and McDonald, 1982; Tingvall, 1987).

It has been reported that pseudosubluxation or physiological anterior displacement of C2 on C3 of more than three millimeters occurs in approximately 24-33% of children less than eight years of age (Dunlap, et al, 1958; Fuchs, et al, 1989; Papavasilou, 1978). In autopsy specimens the elastic infantile vertebral bodies and ligaments allows for column elongation of up to two inches, but the spinal cord ruptures if stretched more than 1/4 inch (Leventhal, 1960). Thus it is difficult to differentiate physiological displacement from pathological dislocation of C2 on C3 in childhood, especially when an x-ray is taken with the child's head in flexion (Swishuck, 1977). Occasionally in young infants, there is a reversal of the normal anterior curve, seen in lateral C-spine x-rays, probably due to the weak, immature cervical musculature (Harris and Edeiken-Monroe, 1987).

If neck motion exceeds tolerable limits, dislocation of vertebrae and possibly injury to the spinal cord can occur. This combination of anatomical features results in lowered protection of the neck in rapid deceleration and if the head is rotated or snapped to the side or to the rear, serious damage might occur to the delicate system of critical arteries or veins of the brain, to nerves, to the vertebrae, and/or the spinal cord itself. The mechanism of pediatric cervical injury is relatively straight forward---head flexion with either a tension or compression component and a relatively restrained torso. Basically, in the frontal-type crash the head continues forward beyond the belted torso. The structure of the child's neck certainly plays a part in the injury. Fuchs, et al (1989) best summarized the reasons for this, including (1) A heavy head on a small body results in high torques being applied to the neck and consequently, high susceptibility to flexion-extension injuries, (2) The lax ligaments that allows a significant degree of spinal mobility (anterior subluxation of up to 4.0 mm at C2-3 or C3-4 may occur as a normal variant), (3) The cervical musculature is not fully developed in the infant allowing for unchecked distracting and displacement forces, (4) The facet joints at C1 and C3 are nearly horizontal for the first several years of life allowing for subluxations at relatively little force, (5) Immature uncovertebral joints of the C2 to C4 levels may not withstand flexion-rotation forces (6) The fulcrum of cervical movement is located higher in young children (C2-3 level than in adults (C5-6).

## THE CHEST

Thoracic injuries in children subjected to impact usually occur to the internal organs. The thoracic walls are thinner and the ribs more elastic in infants and young children than in the adults. Therefore, impact to the thorax of an infant or a small child will produce larger amounts of chest wall deflection onto the vital thoracic organs, e.g. heart, lungs. As clinicians well know, closed cardiac massage in infants can be performed by using only one or two fingers which well demonstrates the highly elastic nature of the chest wall.

At birth the infant heart lies midway between the top of the head and the buttocks. The long axis of the heart is directed horizontally in the fourth intercostal space with its apex lateral to the midclavicular line. These relationships are maintained until the 4th year, and later the heart gradually moves downward, due to the elongation of the thorax, until it comes to lie at the fifth intercostal space with its apex inside the midclavicular line. Until the first year, the width (or length) of the heart is no more than 55% of the chest width taken at the xyphoid line. After the first year, heart width is slightly less than 50% of the chest width (Fig. 11).

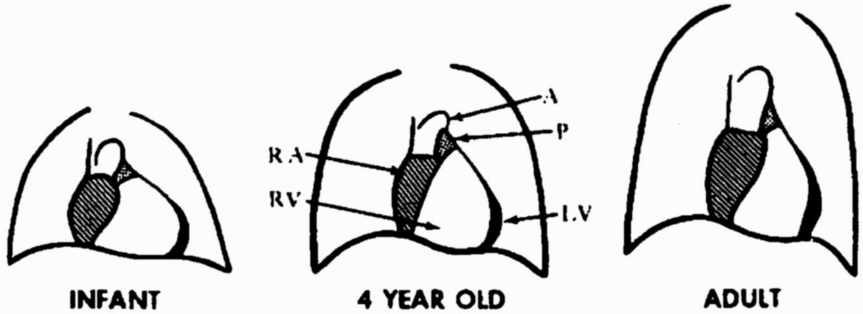


Fig. 11. Schematic diagram of the position
al changes of the heart within the chest at various ages.
(Redrawn from Watson and Lowrey, "Growth and Development of Children.")

At birth the chest is circular, but as the infant grows the transverse diameter becomes larger than the anterior-posterior dimension, giving the chest an elliptical appearance. At birth the chest circumference is about one-half inch smaller than the head. At 1 year the chest is equal to or exceeds head circumference slightly; after 1 year the chest becomes progressively larger in diameter than the head.

Scientists are not entirely in agreement as to the primary biomechanical causation of cardiac trauma during impact in the adult. Researchers such as Stapp (1965) and Taylor (1963) report that pressure is the major factor. However, cardiac rupture has been produced experimentally in animals with the blood volume entirely removed, strongly suggesting that other factors are involved (Roberts et al, 1965). Lasky et al (1968), studying adult humans involved in steering-wheel impacts, believes that aortic laceration occurs at the weakest and narrowest point of the aortic arch, and that this anatomical fact is of biodynamic significance.

Introducing a new consideration, Life and Pince (1968) have demonstrated experimentally in animals that the contractile state of the ventricular myocardium at the instant of impact plays a critical role in whether or not cardiac rupture will occur. Clinical shock with abnormally slow heart and pulse rates (bradycardia) occurs without structural failure in human adult impact tests, and constitutes a primary limitation to the rate of onset (Taylor, 1963).

No thoracic impact data are available for children. Considering the differences between child and adult morphology, impact tolerances for the child are probably considerably less than those of the adult.

## THE ABDOMEN

Although statistically meaningful studies on child abdominal injuries have not been conducted, the effect of blunt abdominal trauma to children, as compared to adults, has been suggested in the literature. Tank et al (1968), noted that only cerebral injuries and burns outrank injury to the abdominal organs as a form of serious accidental injury to children. In adults, blunt injury to the abdominal viscera presents the most difficult diagnosis and treatment, and results in the highest mortality rate (Fonkalsrud, 1966; Orloff, 1966). Thus, any blunt abdominal injury can be potentially serious, but such injuries to the infant and child are much more critical due to their developing and immature structure, large organ relationships, and almost complete lack of overlying muscle or skeletal protection.

The bulge of the newborn abdomen is accentuated by the abdominal viscera pushing forward during respiration against the weak and atonic muscle wall of the abdomen. The right side of the infant and newborn abdomen is especially enlarged due to the low position of the liver which occupies two-fifths of the abdominal cavity. Along the midclavicular line the liver is approximately 2 cm below the costal margins in the newborn; one and one-half cm below the margin for the remainder of the first year; and 1 cm below from 18 months to 6 years. After about the 6th-7th year, the liver is seldom palpable except in abnormal cases. On a weight basis, the liver of the newborn comprises 4% of the total body weight, and by puberty weighs 10 times as much (Watson and Lowery, 1967). The liver, although considered as an abdominal organ, lies almost entirely deep to the right lower ribs and the highly elastic ribs of the child offer minimal protection for this organ from impact.

Posteriorly, a similar relative migration of the bony thorax downward occurs to provide some protection for the spleen, kidneys, and suprarenal glands as the infant ages. At birth, for example, the kidneys occupy a large portion of the posterior abdominal cavity owing to their relatively large size.

In the newborn, the urinary bladder lies close to the lower abdominal wall with only its lower portion located behind the pubic bones. During childhood, much of the bladder descends into the pelvic area where it is more protected by the bony pelvis.

Again, many of the child abdominal viscera are relatively unprotected by bone as compared to the adult. The bladder is located higher, outside the pelvic area, the liver and kidneys are relatively exposed, all being more available to traumatic insult. The liver is an organ which is not well designed for withstanding traumatic insults even in the adult. Traumatic liver injuries produce the highest mortality rate of any abdominal organ (Di Vincenti et al, 1968). With the smaller chest and pelvis of the child, less of the abdominal contents are protected by the rib cage and bony pelvis, and can be more easily injured.

Dimensions of the abdominal area also differ from that of the adult, both proportionately and in relation to position of body organs. Abdominal girth, in general, is about the same as that of the chest during the first 2 years of life. After 2 years, increases in abdominal circumference at the umbilical level do not keep pace with the increases in thoracic girth. Pelvic breadth is another dimension which is less subject to variations in body posture and tonic activity of the muscular abdominal wall. The maximum distance between the external margins of the iliac crests is approximately 3 inches at birth, 5 inches at 1 year, 7 inches at 5 years and 9 inches at 10 years of age. Generally, in the early part of infancy there is little change in trunk form, but after the assumption of erect posture there is a relative reduction in the anterior-posterior diameter of both of the thoracic and abdominal regions, accompanied by a decrease in the relative size of the umbilical region and a relative increase in the lumbar region. These changes continue throughout childhood and early adolescence.

## THE VERTEBRAL COLUMN

Normal development of erect posture involves a gradual transition from the early crawling stages involving interrelationships of the extremities, spine, and pelvis, to the well-balanced weight-bearing relationships typical of the adult. When the infant first stands, the pelvis is tilted far forward on the thighs and an erect posture is first attained in infancy concurrent with the development of the lumbar (low back) curve. As a result of this lumbar curve, combined with increased tonic activity of abdominal wall muscles the infant develops his characteristic sway-back and abdominal prominence which is maintained throughout pre-school years. The infant pelvis gradually rotates upward and forward beginning to establish an adult-like posture. The curvature of the sacrum as seen in the adult is already present at birth; however, in infants the vertebral column above the sacrum is usually straight (Fig. 12).

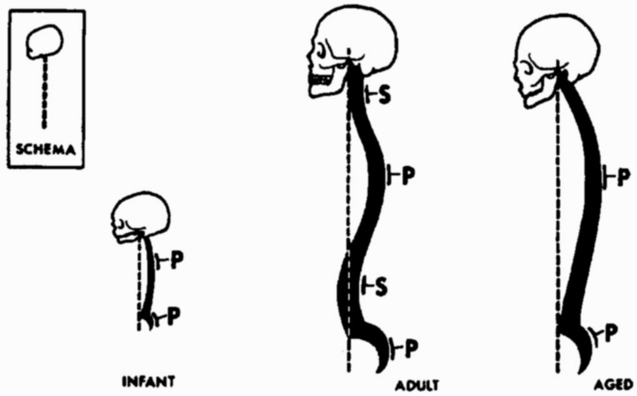


Fig. 12. Curvature of vertebral column emphasizing the development of primary curvatures (P) and secondary curvatures (S). Note: in the infant there are only two primary curves, i.e. thoracic and sacral. In the adult there are secondary curves in the cervical and lumbar regions. In the aged only the primary curves persist. (Modified from Johnson and Kennedy, "Radiographic Anatomy of the Human Skeleton.")

Early in infancy the baby can raise his head while lying prone, and the cervical (neck) curve first becomes well established as the head is held erect and cervical muscles become developed and increase their tone activity. By the 3rd or 4th month the infant can sit with support and by the 7th month can be expected to sit alone. At 8 or 9 months the infant can usually stand with support and then can stand without assistance by 10-14 months.

In the adult, the prominent anterior superior iliac spines are used as anatomical anchor points. But in children these spines are not well developed until about 10 years of age and basically do not yet exist. Rather this anterior pelvic area is a broad gentle curve without a prominent spine as in the adult.

## THE LIMBS

In considering the growth of the extremities it is necessary to examine factors of skeletal embryology and subsequent dimensional changes (Scammon and Calkins, 1929). Considering first the trends in dimensional growth of the limbs, it is generally noted that the lower limbs increase in length more rapidly than do the upper limbs. At about 2 years of age, for example, their lengths are equal but in the adult the lower limb is about on-sixth longer than the upper limb. The adult relations of the different limb segments are well established prenatally; however, there is some reduction in the relative length of the hand and of the foot after birth. At birth the lower limb forms about 15% of the body volume and in the adult reaches about 30%. In contrast the upper limb constitutes about 8%

of the body weight at birth and maintains this same proportionality thereafter.

As in the skull, the long bones of the extremities pass through successive developmental stages which, when compared to adult morphology, make the limb bones less tolerable to trauma. In early development before birth, long bones are typically represented by a shaft of bone which grows in diameter by addition of new bone on its surface with concomitant erosion within the shaft. This development of the shaft can best be described as a tube that progressively increases in diameter. Impact tolerances of children's bones are dependent upon the changing girth of the bone and relative proportions of the marrow cavity and bony walls, as well as the proportions of inorganic and organic materials that form bone tissue. In the early development of bone tissue, organic materials outweigh inorganic components. The degree of flexibility or torsional strength of the bone itself is directly related to the organic component of the bone structure. The preponderance of organic material continues through adolescence after which there is a gradual buildup of inorganic bone substance.

Change in length of long bones is a function of the continued growth of epiphyseal cartilage. In the early development of a long bone the shaft is capped on both ends by cartilage. From late fetal life through puberty bond tissue appears in the cartilage at either end of the shaft but does not attach to the shaft. There is a remaining cartilaginous epiphyseal plate between the bony shaft and the bony epiphyseal ossification center at each end. The surface of the epiphyseal cartilage in contact with the long bone shaft continues to grow which effectively moves or pushes the epiphyseal bone cap away from the shaft. This activity of the epiphyseal cartilage accounts for increases in length of the long bone. Finally, when the adult length is attained for a specific bone as influenced by sex, race, nutrition and endocrine balance, the cartilage of the epiphyseal plate stops proliferation and begins to ossify. Thus, the bony epiphyseal cap is united to the shaft. In females the epiphyses unite sooner so that growth in length ceases earlier by about 2-3 years when compared to males of similar ages. But even in the male most of the fusions of long bone epiphyseal cartilages are completed at about the twentieth year. Obviously, since bone length is a factor of epiphyseal cartilage growth, traumatic displacement of the cartilage out of line with the normal lone axis of the bone can lead to gross limb distortion and malformations.

## Conclusions

Infants and children are not miniature adults. Their anatomy differs from the adult in a number of ways which should be considered in the proper design of occupant restraint systems specific to their age. Within the framework of automobile safety design it should be emphasized that:

(1) The frequency of head injuries in children involved in automobile accidents may be due to the child's proportionately large head and higher center of gravity. As a consequence, infants and children restrained by a lap belt have a greater chance of being projected over the restraining belt because the CG and body fulcrum is located above the belt location.

(2) Observations that the child's head is relatively massive and supported poorly from below have been implicated in head snapping with rapid body deceleration. Such sudden snapping or rotation of the relatively unrestrained child's head can traumatize related nerves, blood vessels, and spinal cord segments.

(3) Contributing to brain injuries of the young child is the relative lack of skull protection since, early in life, the skull is not an intact bony case for the brain but is a series of broadly spaced elastic bones.

(4) Growth rates of different parts of the body vary with age. For example, the mid-point of the body is above the navel at birth, slightly below it a 2 years of age and nearer the pubic bones at sixteen years.

(5) Since growth of the child is dependent upon the normal activity of growth centers, protection of these centers is vital. Abnormalities of body stature and limb mobility might result from injury to growth centers of the extremities. Similarly, in the head, the arrangement of teeth as well as the facial profile can be affected by traumatic injuries to the facial growth centers.

(6) Unlike the adult, the organs of the chest are housed in an elastic and highly compressible thoracic cage. Organs as the lungs and heart are extremely vulnerable to nonpenetrating impacts to the chest. The smaller rib cage also means less protection is offered to larger abdominal organs which would normally receive some protection form the larger stronger rib cage of the adult. The highly elastic structure of the thoracic cage is not amenable to direct trauma or loading of webbed restraints in children.

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